CHAPTER 5

STRUCTURAL DESIGN OF SEWERS

5-1. General. The structural design of a sewer requires that the supporting strength of the pipe as installed must equal or exceed the external loading multiplied by a factor of safety. The following criteria for structural design of sewers are based on the assumption that sewers will be laid in trenches entirely below the natural ground surface and backfilled with suitable materials, that the sides of the trench will be nearly vertical below the top of the pipe and will have slopes no flatter than one horizontal to two vertical above the pipe, and that the trench width at the top of the pipe will be relatively narrow. In general, the trench width will be limited to the maximum allowed or recommended by the pipe manufacturer.

5-2. Loads on sewers. There are three kinds of external loads to which a sewer laid in a trench may be subjected. They are (1) loads due to trench filling materials, (2) uniformly distributed surface loads, such as stockpiled materials or loose fill, and (3) concentrated surface loads, such as those from truck wheels.

a. Trench fill loads. The Marston formula will be used for calculating loads on rigid conduits as shown in the following equation:

$$W_t = C_t w B_t^2$$

where:

W_t = vertical load on conduit in pounds per lineal foot
C_t = trench load coefficient for buried conduits
w = unit weight of trench fill materials in pcf, and
B_t = horizontal width of trench at top of pipe in feet

For calculation of loads on flexible conduits the prism formula will be used as shown in the following equation:

$$W_t = H_w B_c$$

where:

H_w = height of fill from top of pipe to ground surface in feet
B_c = horizontal width or outside diameter of pipe in feet

In the absence of soil density measurements, the weight per cubic foot of various materials may be taken as 120 pounds. The load coefficient C_t is a function of the fill height H divided by the width of trench

B_t, and will be determined from figure 5-1. An examination of the Marston formula will show the importance of the trench being as narrow as practicable at and below the top of the pipe.

b. Uniformly distributed loads. Distributed loads on rigid and flexible conduits will be calculated by the following equation:

$$W_d = C_s p F B_c$$

where:

W_d = vertical load on the conduit in pounds per lineal foot
C_s = surface load coefficient for buried conduits
p = intensity of distributed load in psf
F = impact factor, and
B_c = horizontal width or outside diameter of pipe in feet

The load coefficient C_s is dependent upon the area over which the load p acts. It will be selected from table 5-1 as a function of the area width D and length M, each divided by twice the height of fill H. The impact factor F will be determined with the use of table 5-2.

Table 5-2. Impact Factor (F) vs. Height of Cover

Height of Cover, ft.	Installation Surface Condition: Highways	Railways	Runways	Taxiways, Aprons, Hardstands, Run-up Pads
0 to 1	1.50	1.75	1.00	1.50
1 to 2	1.35	*	1.00	**
2 to 3	1.15	*	1.00	**
Over 3'	1.00	*	1.00	**

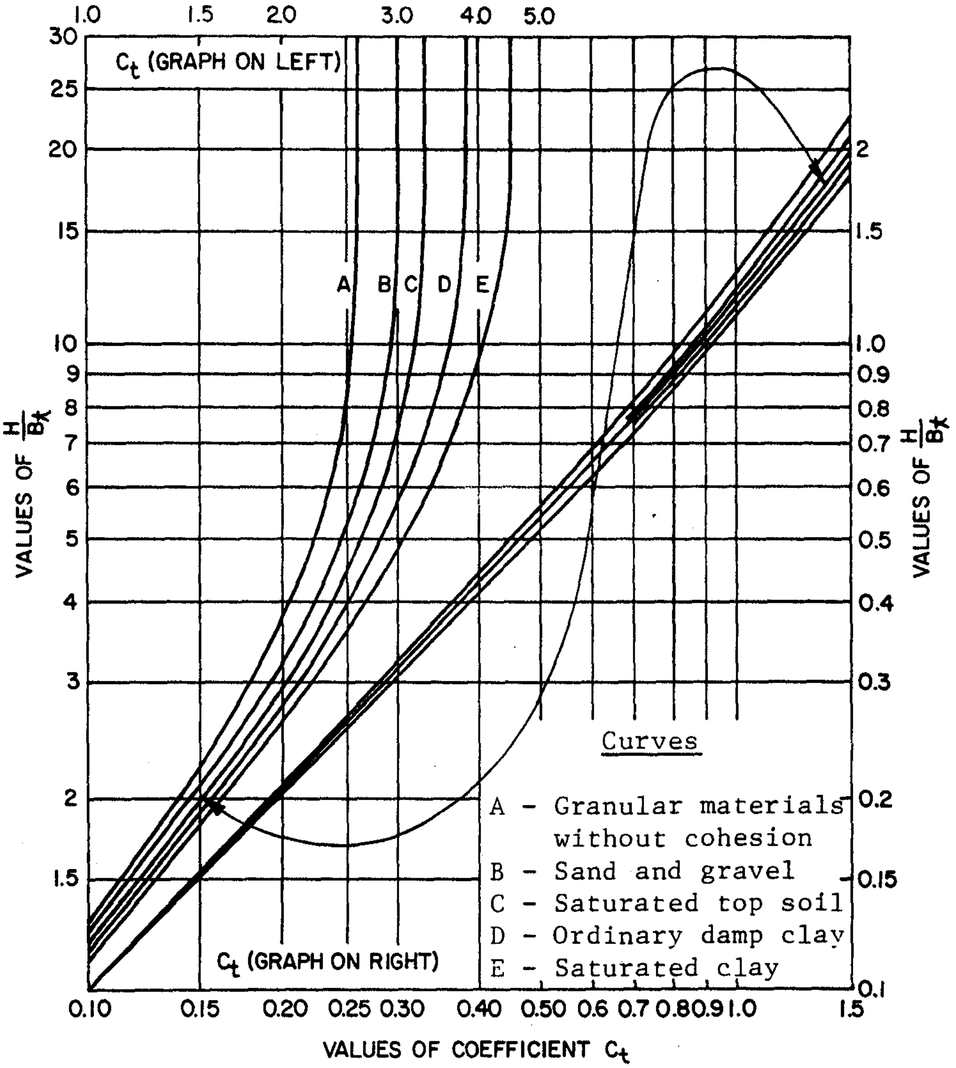
* Refer to data available from American Railway Engineering Association (AREA)
** Refer to data available from Federal Aviation Administration (FAA)

Note that for a static load, F = 1.0.

Source: Handbook of PVC Pipe - Design and Construction by Uni-Bell Plastic Pipe Association, Second edition, 1982, p. 151.

c. Concentrated loads. The formula to be used for calculating concentrated loads on rigid and flexible conduits is given by the following equation:

$$W_c = C_s P F / L$$



DESIGN AND CONSTRUCTION OF SANITARY AND STORM SEWERS - WPCF MANUAL OF PRACTICE NO. 9 BY WATER POLLUTION CONTROL FEDERATION, 1970, P. 189.

FIGURE 5-1. TRENCH LOAD COEFFICIENTS

Table 5-1. Surface Load Coefficient

Values of Load Coefficients, C_s, for Concentrated and Distributed Superimposed Loads Vertically Centered Over Conduit*

$\frac{D}{2H}$ or $\frac{B_c}{2H}$	$\frac{M}{2H}$ or $\frac{L}{2H}$ 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5	2.0	5.0
0.1	0.019	0.037	0.053	0.067	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.345	0.355	0.360
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.440	0.454	0.460
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.548
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.624
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.584	0.597	0.628	0.650	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.742	0.766	0.784
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.774	0.800	0.816
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.440	0.525	0.596	0.650	0.703	0.742	0.774	0.820	0.861	0.894	0.916
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.894	0.930	0.956

*Influence coefficients for solution of Holl's and Newmark's integration of the Boussinesq equation for vertical stress.

Source: Design and Construction of Sanitary and Storm Sewers - WPCF Manual of Practice No. 9 by Water Pollution Control Federation, 1970, p. 206.

where:

W_c = vertical load on the conduit in pounds per lineal foot
C_s = surface load coefficient for buried conduits
P = concentrated load in pounds
F = impact factor, and
L = effective length of conduit in feet

An effective length of 3 feet will be used in all cases, except where pipe lengths are less than 3 feet, in which case the actual length of pipe will be used. The load coefficient C_s is a function of conduit width B_c and effective length L, each divided by twice the height of fill H. Determination of the load coefficient will be by the use of table 5-1, and impact factor F will be selected from table 5-2. It will be noted from table 5-2 that the effect of a concentrated or distributed load diminishes rapidly as the amount of cover over the sewer increases.

5-3. Supporting strength of sewers. A sewer's ability to resist external earth and superimposed loads depends not only on the pipe's inherent structural capability, but also on the method of installing the pipe in the trench, i.e., class of bedding, type of backfill materials, percentage of compaction, etc.

a. Rigid conduit. Pipe strength in general will be determined by the three-edge bearing test or TEBT (termed crushing strength in various pipe specifications) and is expressed in pounds per lineal foot. However, since this does not represent the actual field loading conditions, a relationship must be established between calculated load, laboratory test strength and field support strength. The following definitions and terminology will be used to develop field support strength.

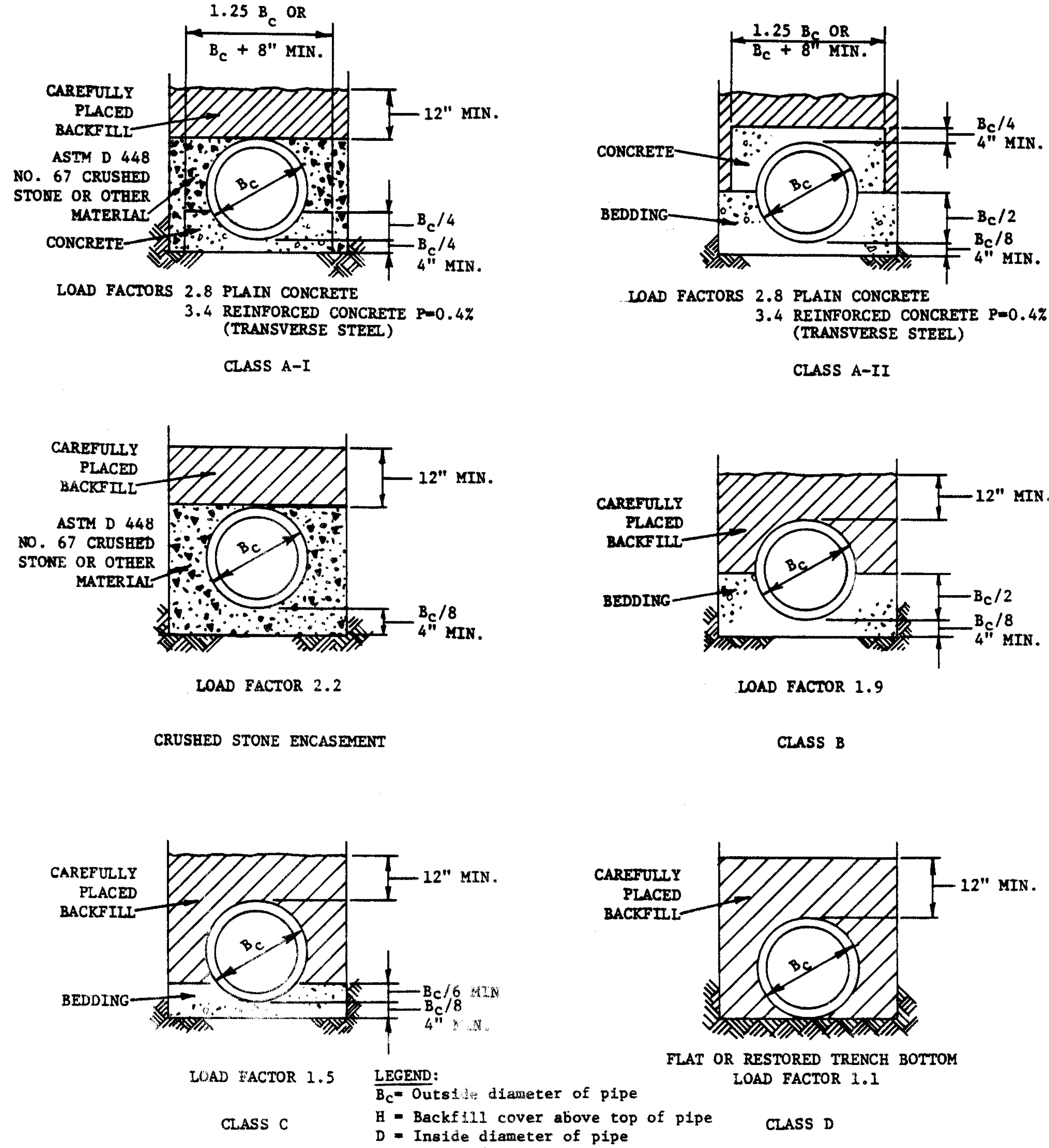
(1) Field support strength is the maximum load in pounds per lineal foot which the pipe will support when installed under specified trench bedding and backfill conditions.

(2) The load factor is the ratio of the field support strength to the three-edge bearing test and will be selected from figure 5-2 depending on the class of bedding used.

(3) Safe supporting strength is the field support strength divided by a factor of safety, equal to 1.5 for rigid conduits.

(4) The total load calculated in paragraph 5-2 must not exceed the safe supporting strength.

(5) An additional parameter is the working strength, which is the three-edge bearing strength divided by the factor of safety.



LEGEND:
B_c = Outside diameter of pipe
H = Backfill cover above top of pipe
D = Inside diameter of pipe
d = Depth of bedding material below pipe
A = Area of transverse steel in the cradle of arch expressed as 3 percent of the area of concrete at the invert or crown

NOTE: For rock or other incompressible material, the trench should be overexcavated a minimum of 6 inches and refilled with granular material.

CLAY PIPE ENGINEERING MANUAL BY NATIONAL CLAY PIPE INSTITUTE, 1982, P. 52-53.

FIGURE 5-2. LOAD FACTORS AND CLASS OF BEDDING

b. Special rigid conduit testing. For piping not tested and rated by the TEBT method, other strength criteria will be applied as follows. Reinforced concrete pipe strength will be based on D-loads at the 0.01-inch crack load and/or ultimate load as described in the ACPA Concrete Pipe Handbook. For ductile iron pipe, ANSI A21.50 will be used to calculate the required pipe thickness classification in relation to field loadings. The strength of cast iron soil pipe, which normally will be used for building connections only, should be evaluated as outlined in the CISPI Cast Iron Soil Pipe and Fittings Handbook.

c. Flexible conduit. The capability to resist pipe deflection and buckling under loads is the primary criterion used in the structural design of flexible conduit. When loaded the pipe walls will deflect, thereby creating a passive soil support at the sides of the conduit. This pipe-soil system is essential in providing a high effective strength, often enabling it to out perform rigid pipe under identical loading and soil conditions. While the three-edge bearing strength is an appropriate measure of load carrying capacity for rigid conduits, it is not applicable for describing flexible pipe stiffness. Because a flexible conduit must successfully interact with the surrounding soil to support its load, the method of backfill placement, types of materials used, soil compaction, etc., are more critical than trench width or bedding. PVC will be designed as recommended by the manufacturer.

d. Pipe installation.

(1) Bedding. Figure 5-2 depicts various classes of bedding generally used when installing sewers.

(2) Backfill and compaction. Backfill materials and compaction requirements will be included in the specifications. The possible use of locally available materials for backfill will be investigated. Compaction requirements will be designated for the particular soil and moisture content at the site.

(3) Installation manuals. Installation manuals for the particular types of pipe to be specified will be reviewed to ascertain that bedding, backfill, and compaction are adequate for the existing subsurface conditions at the site.

5-4. Special designs. Sewers should be routed to avoid areas where soils investigations indicate poor soil conditions, rock, or rough terrain. In cases where these conditions cannot be avoided, the following special design approaches are to be considered.

a. Unsatisfactory soil conditions. In situations where unstable materials occur at shallow depths, it will generally be acceptable to overexcavate native soil to just below the trench bottom and replace with a layer of crushed stone, gravel, or other coarse aggregate. Concrete or wooden cradles can be used in lieu of aggregates.

b. Installation in rock. Where sewers must be constructed in rocky terrain, trenches will be sufficiently wide to provide clearance between the sides and bottom of the pipe, and any rock in the trench. Pipe must be installed to avoid all contact with rock, or any other unyielding material in the trench. A granular type bedding or concrete cradle will normally be provided along the pipe bottom, and trenches will be backfilled with satisfactory materials.

c. Aboveground sewers. Sewers are normally laid underground, and at sufficient depths to be protected from impact and freezing. However, in cases where valleys, watercourses, structures, or other obstacles must be crossed, it is sometimes more advantageous to install sewers aboveground. Sewers supported from bridges, piers, suspension cables, or pipe beams, etc., will be designed with adequate structural capability. Protection against freezing and prevention of leakage are important design considerations. Expansion jointing may also be required.

d. Jacking, boring, and tunneling. In situations where sewers must be constructed more than 15 feet below ground surface, through embankments, under railroads, or where surface conditions make it difficult or impractical to excavate open trenches, it will be necessary to install the pipe by other methods. In these cases, pipe may be pushed, jacked, bored, or tunneled into place. A casing pipe will normally be required for sewers installed under railroads, primary access roads and airfield pavements. The void space between the sewer pipe and casing will be filled with special aggregates capable of being blown into place, or with commercially available polyethylene or other type spacers, saddles, and seals. Depending on soil resistance, rigid extra strength pipe can be forced underground by machine for distances of 50 to 150 feet.